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(56) Documents Cited

**WO 99/25030 A1 WO 93/26049 A1 US 5232862 A**

(58) Field of Search

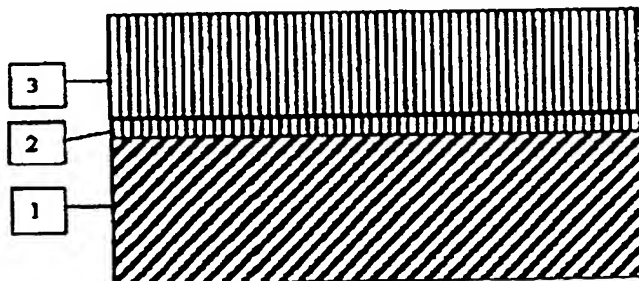
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**KLDBX KLDX**  
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**ON LINE, W.P.I., EPODOC, JAPIO**

(54) Abstract Title

**Growing semiconductor layers**

(57) A method of growing a Group III-nitride semiconductor layer 3 on a lattice mismatched substrate 1 comprises depositing an amorphous or polycrystalline buffer layer 2 of  $B_xAl_yGa_zIn_{1-x-y-z}N$  alloy on the substrate and recrystallizing the buffer layer before epitaxially growing the semiconductor layer. The substrate may comprise sapphire and the semiconductor layer may be GaN.

Fig. 1c



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Fig. 1a

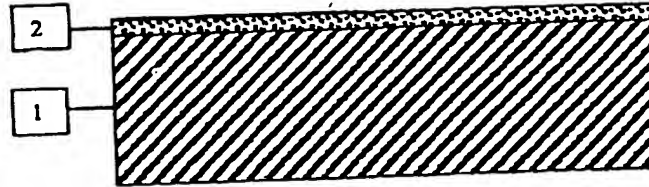


Fig. 1b

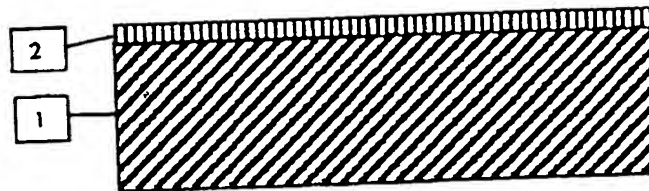


Fig. 1c

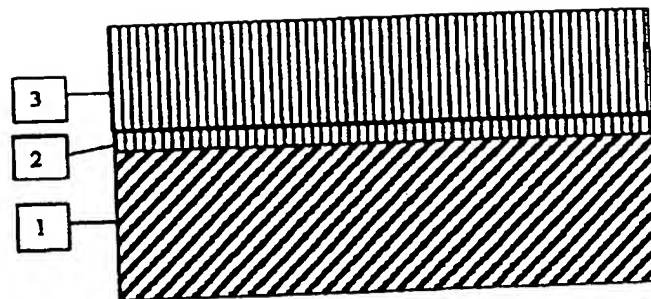


Fig.2a

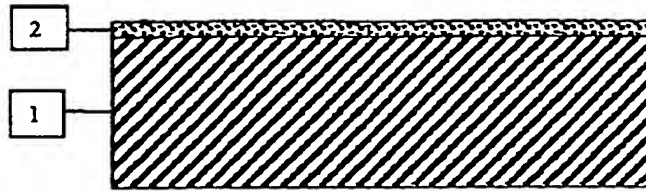


Fig.2b

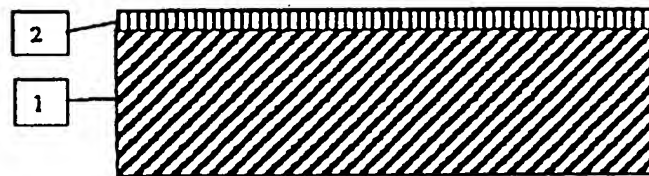


Fig.2c

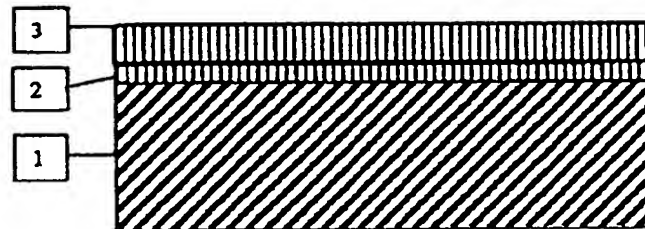


Fig.2d

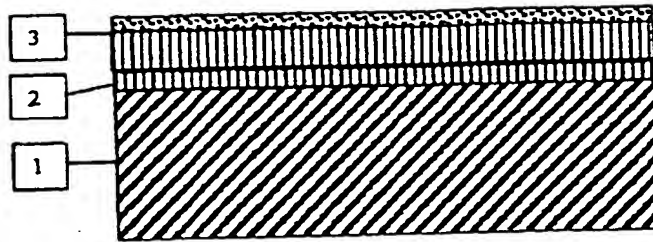


Fig.2e

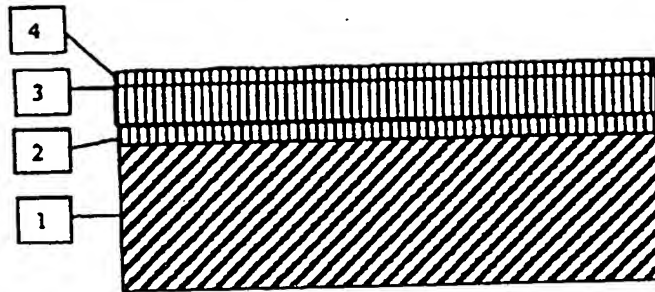
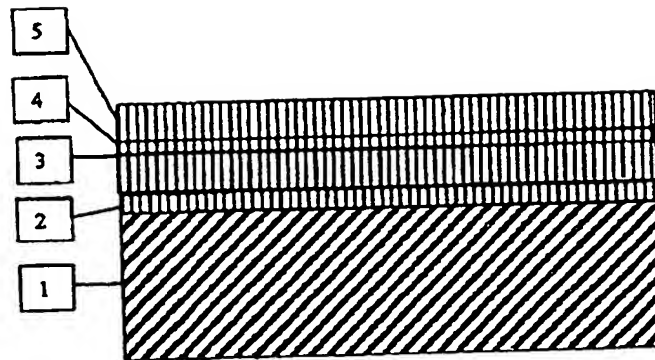


Fig.2f



**EPITAXIAL GROWTH METHOD OF  
III-NITRIDE SEMICONDUCTORS ON  
HIGHLY MISMATCHED  
SUBSTRATES WITH USE OF  
 $B_xAl_yGa_zIn_{1-x-y-z}N$  BUFFER  
NUCLEATION LAYER**

**BACKGROUND OF THE INVENTION**

**1. Field of the Invention**

The present invention generally relates to fabrication of III-nitride semiconductor devices by growth of epitaxial semiconductor layers on highly lattice mismatched substrates. More particularly, the invention deals with a special buffer nucleation layer which accommodates high mismatch.

**2. Description of the Prior Art**

Epitaxial growth of III-nitride semiconductor on highly mismatched substrates results in extremely strained semiconductor layers. This strain gives rise to the formation of many extended defects such as dislocations, grain boundaries, stacking faults, inversion domains etc., and it is generally responsible for the poor quality of the grown semiconductor layers. Buffer nucleation layers have been used during several decades for the strain reduction and improving quality of the grown semiconductor layers. Usually buffer nucleation layers for epitaxial growth of III-nitride semiconductor on highly mismatched substrates are made of AlN, GaN compounds or  $Al_xGa_yIn_{1-x-y}N$  alloys.

The present invention employs the buffer nucleation layer made of boron containing  $B_xAl_yGa_zIn_{1-x-y-z}N$  alloys.

**SUMMARY OF THE INVENTION**

It is an object of the present invention to provide a growth method that allows to eliminate the strain resulting from high

mismatch between the lattice parameters of the III-nitride semiconductor and a substrate on which this semiconductor is grown.

This invention states the use of the boron containing  $B_xAl_yGa_zIn_{1-x-y-z}N$  alloy buffer nucleation layer in the growth process of III-nitride semiconductors on highly lattice mismatched substrates.

Providing boron containing alloys as materials for depositing nucleation layers increases density of nuclei. The boron containing alloys have higher crystallization temperature comparing to III-nitride alloys without boron. The higher crystallization temperature results in lower mobility of adsorbed atoms over the surface of the substrate. This leads to higher density of nuclei in the nucleation layer and smaller nuclei sizes. After the recrystallization of the buffer nucleation layer this results in improved structural quality of epitaxial layers.

The high chemical activity of boron atoms compared with other III-group elements is also favorable for the formation of higher density of nucleation sites.

The other advantage of boron containing alloys in the buffer nucleation layer is the admixture of BN graphite phase which reduces the hardness and increases the plasticity of the buffer nucleation layer that in turn results in better strain relaxation of III-nitride epilayers grown on highly mismatched substrates.

Using  $B_xAl_yGa_zIn_{1-x-y-z}N$  alloys comparing with AlN, GaN compounds or  $Al_xGa_yIn_{1-x-y}N$  alloys, provides wider range of lattice constant variation and wider possibility for mismatch reduction for various substrates.

The growth process with use of the buffer layer consists of the following main three stages.

1. The thin amorphous or polycrystalline buffer nucleation layer is deposited on the substrate at the temperature in the range 300 - 800 C.

2. Then a recrystallization of the buffer nucleation layer at temperature 1000 - 1500 C is performed.
3. Then the epitaxial III-nitride semiconductor layer is grown on the recrystallized buffer nucleation layer at temperature 700 - 1500 C.

#### BRIEF DESCRIPTION OF THE DRAWINGS

Figs. 1a-c, illustrates the use of the boron containing  $B_xAl_yGa_zIn_{1x-y-z}N$  alloy buffer nucleation layer in the growth process of III-nitride semiconductors on highly lattice mismatched substrates.

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The preferred embodiments of the present invention are illustrated in Figs. 1a-c. These figures show the principal stages of the growth of the epitaxial semiconductor layer using the boron containing  $B_xAl_yGa_zIn_{1x-y-z}N$  alloy buffer nucleation layer.

At first stage, shown in Fig.1a, the amorphous or polycrystalline buffer nucleation layer 2 with the thickness from 5 Å to 500 Å is deposited on the substrate 1 at temperature in the range 300 - 800 C.

At second stage, shown in Fig.1b, a recrystallization of the buffer nucleation layer 2 at temperature 1000 - 1500 C is performed.

At third stage, shown in Fig.1c, the epitaxial III-nitride semiconductor layer is grown on the recrystallized buffer nucleation layer at temperature 700 - 1500 C.

The advantages of using boron containing  $B_xAl_yGa_zIn_{1x-y-z}N$  alloys in the buffer nucleation layer are:

1. Boron containing alloys as materials for depositing nucleation layers reduce nuclei sizes and increase density of nuclei. After the recrystallization of the buffer nucleation layer, this results in improved structural quality of epitaxial layers.

2. The high chemical activity of boron atoms compared with other III-group elements is also favorable for the formation of higher density of nucleation sites.
3. The admixture of BN graphite phase reduces the hardness and increases the plasticity of the buffer nucleation layer that in turn results in better strain relaxation of III-nitride epilayers grown on highly mismatched substrates.
4.  $B_xAl_yGa_zIn_{1-x-y-z}N$  alloys comparing with AlN, GaN compounds or  $Al_xGa_yIn_{1-x-y}N$  alloys, provide wider range of lattice constant variation and wider possibility for mismatch reduction for various substrates.

Thus, the use of the boron containing  $B_xAl_yGa_zIn_{1-x-y-z}N$  alloy buffer nucleation layer allows to grow the high quality epitaxial III-nitride semiconductor layers on highly mismatched substrates.

The invention will be more fully understood by reference to the following examples

#### EXAMPLE 1

At first stage, shown in Fig.1a, the buffer nucleation layer 2 of  $B_{0.1}Ga_{0.9}N$  alloy with the thickness 200 Å is deposited on the sapphire substrate 1 at temperature 500 C.

At second stage, shown in Fig.1b, the temperature is risen up to the growth temperature 1000 C of the GaN semiconductor layer. The temperature rise causes recrystallization of the buffer layer 2 as shown in Fig.1b.

Then 2 µm thick GaN epitaxial layer 3 is grown on the recrystallized layer 2.

#### EXAMPLE 2

At first stage, shown in Fig.2a, the first buffer nucleation layer 2 of  $B_{0.1}Ga_{0.9}N$  alloy with the thickness 200 Å is deposited on the sapphire substrate 1 at the temperature 500 C.



At second stage, the temperature is risen up to the growth temperature 1000 C of the GaN semiconductor layer. The temperature rise causes recrystallization of the first buffer layer 2 as shown in Fig.2b.

At the third stage, temperature is risen up to the temperature 1150 C to grow the 500 Å thick intermediate GaN epitaxial layer 3 as shown in Fig.2c.

Then, the second buffer nucleation layer 4 of  $B_{0.1}Ga_{0.9}N$  alloy with the thickness 200 Å is deposited on the first GaN epitaxial layer 3 at the temperature 500 C as shown in Fig.2d.

After that, the temperature is risen up to the growth temperature 1000 C for recrystallization of the second buffer nucleation layer 4 c.

Finally, then 2 μm thick the GaN epitaxial layer 5 is grown on the second buffer nucleation layer 4 as shown in Fig.2f.

### EXAMPLE 3

At first stage, shown in Fig.1a, the buffer nucleation layer 2 of  $B_{0.1}Ga_{0.9}N$  alloy is deposited on the sapphire substrate 1 simultaneously with temperature rise from 600 C up to 1000 C with the rate of temperature variation 5 C per second.

At second stage, shown in Fig.1b, the 2 μm thick GaN epitaxial semiconductor layer 3 is grown on the recrystallized buffer nucleation layer 2.

### CLAIMS

1. An epitaxial growth method of III-nitride semiconductor layers and structures on highly mismatched substrates using the  $B_xAl_yGa_zIn_{1-x-y-z}N$  alloys in the buffer nucleation layer comprising:

the deposition on a substrate of the amorphous or polycrystalline buffer nucleation layer with the thickness from 10 Å to 1000 Å at the temperature in the range 300 - 800 C;

the recrystallization of the buffer nucleation layer at temperature 1000 - 1500 C during the time period in the range 5 - 500 sec;

the epitaxial growth of a III-nitride semiconductor layer or structure on the recrystallized buffer nucleation layer at the temperature 700 - 1500 C.

2. The buffer nucleation layer made of ternary  $B_xAl_{1-x}N$  alloys, where  $0 < x \leq 1$ .

3. The buffer nucleation layer made of ternary  $B_xGa_{1-x}N$  alloys, where  $0 < x \leq 1$ .

4. The buffer nucleation layer made of ternary  $B_xIn_{1-x}N$  alloys, where  $0 < x \leq 1$ .

5. The buffer nucleation layer made of  $B_xAl_yGa_zIn_{1-x-y-z}N$  alloys, where  $0 < x \leq 1$ ,  $0 \leq y \leq 1$ ,  $0 \leq z \leq 1$ ,  $x+y+z \leq 1$ .

6. An epitaxial growth method of III-nitride semiconductor layers and structures on highly mismatched substrates using the  $B_xAl_yGa_zIn_{1-x-y-z}N$  alloys in the buffer nucleation layer comprising:

the continuous deposition on a substrate of the amorphous or polycrystalline buffer nucleation layer with the thickness from 50 Å to 1000 Å at the rising temperature from 300 - 800 C to 800 - 1500 C with the temperature rising rate in the range from 1 - 10 degree per second.

the epitaxial growth of a III-nitride semiconductor layer or structure on the recrystallized buffer nucleation layer at the temperature 700 - 1500 C.

7. The use for the epitaxial growth of III-nitride semiconductor of 1 to 10 buffer nucleation layers made of  $B_xAl_yGa_zIn_{1-x-y-z}N$  alloys, where  $0 < x \leq 1$ ,  $0 \leq y \leq 1$ ,  $0 \leq z \leq 1$ ,  $x+y+z \leq 1$  with intermediate epitaxial III-nitride semiconductor layers.



Application No: GB 9920048.7  
Claims searched: All

Examiner: COLIN STONE  
Date of search: 6 December 1999

**Patents Act 1977**  
**Search Report under Section 17**

**Databases searched:**

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:  
UK Cl (Ed.Q): H1K(KLDBA,KLDBB,KLDBM,KLDBT,KLDBX,KLDX)  
Int Cl (Ed.6): H01L  
Other: ON LINE,W.P.I.,EPODOC,JAPIO

**Documents considered to be relevant:**

Category	Identity of document and relevant passage	Relevant to claims
X	WO93/26049 A1 APA OPTICS (See page 4 line 35-page 5 line 6)	2-5
X	US 5232862 GENERAL MOTORS	2-5

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
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